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Potter's Wheel in the Iron Age in Central Europe: Process or Product Innovation?

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Abstract The use of a rotational device for forming ceramic objects represents a fundamental innovation in pottery technology. This work addresses aspects of the transmission of this technological innovation on the basis of technological and provenance analysis of Iron Age pottery in a selected region of Eastern Bohemia. The possible trajectories of the innovative process are approximated specifically through the polarities between product and process innovation and transmission of cultural traits in open and closed learning networks. Apart from standard methods of petrographic and geochemical analysis, this analysis employs innovative methodology for identification of pottery-forming techniques. The results indicate the effects of various mechanisms of cultural transmission which shaped the evolution of techniques in the Iron Age society. The technological changes can be explained by shifting accents on product and process performance characteristics in changing selective environments.

Keywords Technological innovation · Cultural transmission · Pottery technology · Potter's wheel · La Tène period · Central Europe · Eastern Bohemia

Introduction

The potter's wheel represents one of the fundamental technological innovations that emerged parallel to cultural, social and economic transformations in the Iron Age in temperate Europe. Wheel-made pottery appeared in temperate Europe during the late Hallstatt period. Two separate zones of spreading of wheel-made pottery can be distinguished. The first wheel-made pottery in Transnistria and in the Carpathian Basin has been linked to Greek colonies established in the Black Sea region (Fig. 1: A; Romsauer 1991). Eastern European pottery tradition probably did not influence the

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formation of La Tène technological traditions. Greater importance in this respect can be attributed to the western European tradition called "geriefte Drehscheibenkeramik", originally extending through south-western Germany, eastern France and Switzerland (Fig. 1: B; *e.g.*, Tappert 2012; Augier *et al.* 2013). The technological and stylistic ideas of this tradition are thought to have originated in the Mediterranean (Dehn 1963; Lang 1974; Kimmig 1982; Balzer 2009). At least in the La Tène A period, this tradition spread to the east where a distinctive tradition of wheel-made pottery, usually with stamp decoration, was established (Fig. 1: C; Schwappach 1975; Tappert 2006, 2012).

The technique persisted in the repertoire of forming techniques throughout the La Tène period, but evidence for its use in Central Europe can no longer be found for the period of deep economic, social and cultural changes related to the decline of the La Tène culture in the second half of the first century BC. The epilogue of the first spreading of these innovations in Central Europe emphasises the fundamental links between the social, cultural and economic conditions and the use of a particular technological phenomenon.

The evidence for the spread of the potter's wheel in temperate Europe suggests the rapid acquisition of complex and discontinuous technological behaviour. The transmission of such novelty is facilitated by cultural learning mechanisms (*learning biases*), through which learners non-randomly adopt a new cultural variant on the basis of its interactions with people and the environment (*content* or *direct biases*) or the adoption arises from the learning context (*context* or *indirect biases*) (Boyd and Richerson 1985; Henrich and McElreath 2003, 2007). These interactions are facilitated by performance

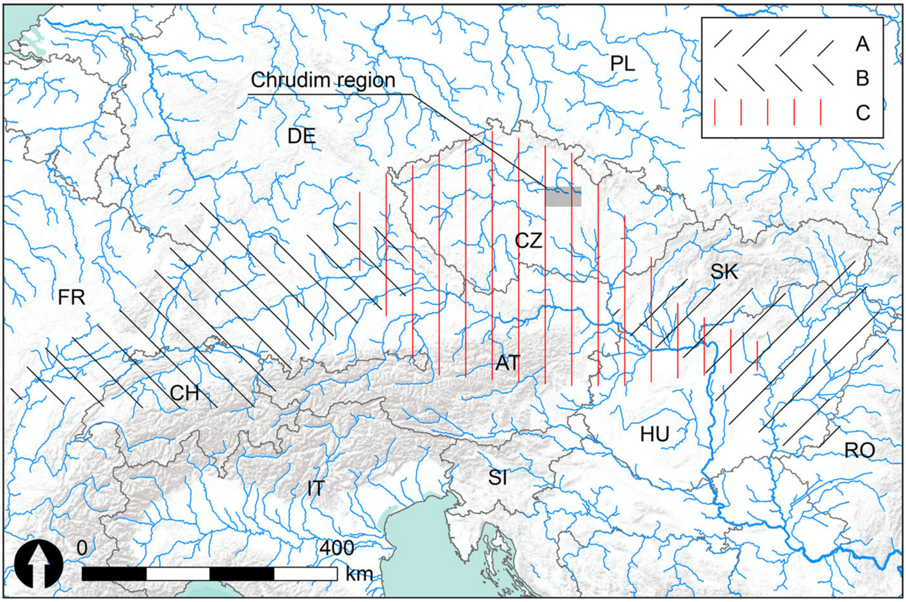

Fig. 1 Main areas of distribution of the discussed groups of the late Hallstatt and the early La Tène wheel-made pottery in Central Europe with indication of the region selected for the analysis (*grey rectangle*). *A*—Vekerzug pottery, first wheel-made pottery in Transnistria and in the Carpathian Basin; *B*—"geriefte Drehscheibenkeramik", the first wheel-made pottery in south-western Germany, eastern France and Switzerland; *C*—La Tène A wheel-made pottery with stamped decoration (sources for the terrain base map: ESRI, USGS and NOAA)

of the new manufacturing process as well as the performance of its products (Braun 1983; Schiffer and Skibo 1987; Lemonnier 1992; O'Brien *et al.* 1994; Fitzhugh 2001; Skibo and Schiffer 2001, 2008; Schiffer 2004). The performance characteristics of a culturally transmitted variant that affect its permanency and transmission relative to other similar phenomena define its "cultural fitness" (Durham 1991; Mesoudi 2010). The aspect of how these innovations perform compared to the established technological processes can be a starting point for examination of their spreading and changes. This is not a simple question when applied to use of the potter's wheel. To begin with, we have to abandon the term potter's wheel. So far, we have used the term as a simplified label for an innovation which represents a system of interrelated components—materials, tools and gestures. The potter's wheel can be defined as a pottery-forming device facilitating the use of rotational kinetic energy for forming. Such a device must meet particular technical parameters related to maintenance of the generated rotational energy. This parameter has been used to differentiate among various types of rotational devices (Childe 1954; Foster 1959; Rieth 1960; Jeffra 2011). The potter's wheel is one of the possible components of an innovation putting into practice the general idea (invention) that rotation of the clay object can be utilised to form it. However, more innovations based on this invention are possible. The different means of application of the concept imply different performance characteristics of the respective techniques. In order to understand the potential cultural fitness of these innovations, we need to describe the possible variability.

The application of this particular concept in an environment where it has not been previously used is a significant cognitive change requiring qualitatively new skills and can thus be regarded as discontinuous (Roux and Corbetta 1989; Roux 2003, 2008). Moreover, Roux (2010) sees two other discontinuities in the technological evolution of the use of rotation for forming. The first is the use of rotational energy for transforming clay walls made by a different technique, and the second is the use of rotational energy to transform a clay mass. Thus, the possible innovations based on the concept of the use of rotation in forming can be classified into three groups based on these discontinuities representing significant differences in the contribution of rotational energy in the forming and skills required to master the use of a rotational device (*cf.* Foster 1959; Nicklin 1971; Kramer 1985; Roux and Corbetta 1989; Gelbert 1997; Roux and Courty 1998; Thér *et al.* 2015).:

(a) The vessel is formed by some hand-building technique, and subsequently, the rotation of the vessel is used to even the surface and correct the shape (hereinafter referred to as *wheel finishing*).[1] Minor transformations of the object performed by wheel finishing do not require significant contribution of rotational energy in forming. This use of rotation requires specific skills, but the time needed to learn such skills is not radically different from the requirements of the respective hand-

[1] Pottery formed by any of the techniques that utilises rotational energy is subsumed under the term wheel-made pottery. We are aware that wheel finishing is feasible without using a potter's wheel, and, in this respect, the terms wheel-made and wheel-finished are inaccurate. However, we avoided the use of more exact and complicated terms for pottery formed with the use of rotation without any specification of the rotational device and decided to use generally understandable terms for the sake of readability.

building techniques and also time requirements needed to complete the vessel are, in principle, comparable.

(b) Secondary forming technique using rotational energy—a roughout of the vessel is formed by some hand-building technique, and subsequently, rotational energy is used in shaping and thinning of the vessel walls (hereinafter referred to as *wheel shaping*). If walls are thinned using rotation of the vessel, the entire shape of the vessel is transformed (or at least expanded). This requires means to ensure effective utilisation of rotational energy and the development of basic skills related to handling and controlling the transformation. These skills are attainable by apprenticeship lasting substantially longer than the respective hand-building techniques, but the entire forming process has little potential to be significantly more time efficient compared to the respective hand-building techniques that are employed without the contribution of rotational energy.

(c) The entire forming sequence is performed using rotational energy—*wheel throwing*. This technique is significantly more efficient than wheel finishing and shaping in terms of the time needed to complete the vessel. However, mastering this technique requires a radical change in skills, with greater demands on their acquisition compared to the previous types.

The performance characteristics of techniques theoretically play a role if the technology is transmitted by cultural biases taking into account the skills, success or prestige of the potters that use the novel technique. The reasons for imitation in this respect can be (a) time efficiency or (b) extraordinary visual performance of the process. Time efficiency could play a role only if we consider the wheel-throwing variant. The extraordinary visual performance of throwing fascinates observers even now, and this is why throwing is a common and rewarding component of public demonstrations of handicrafts. This performance is proportional to the degree of the contribution of rotational energy in forming. It is the most striking when the object is thrown from a lump of clay. On the other hand, use of rotational energy limited to the finishing of an object lacks the impression that the clay transforms itself with little contribution (magical touch) from the potter's hands.

In many cases, potters did not utilise rotational device to its full extent—as in wheel throwing (*e.g.*, Foster 1959; Nicklin 1971; Rye and Evans 1976; Vossen 1990). The persistent use of wheel finishing or shaping after the initial development or acceptance of the new forming concept has been documented in various archaeological contexts (*e.g.*, Courty and Roux 1995; Roux and Courty 1998; Knappett 1999, 2004; Berg 2007; Jeffra 2011; Gauss *et al.* 2015). The performances of technological behaviour can hardly explain the spreading of the innovative behaviour in these cases. However, a technological innovation can also be characterised in terms of its products. Products can be viewed as a set of sensory performances achievable by using the technique. We use the term product innovation to indicate a situation when these performances are under selective control and shape the innovation process. Product innovation leads to a product with new sensory performance. The effort to achieve these properties shapes the changes in the production process. Process innovation is the opposite situation when the performances of the manufacturing process are under selective control. A new process may or may not consequently change some characteristics of the products (*cf.* Elster 1983).

The use of rotation for pottery forming is essentially process innovation—the same type of product (ceramic vessel) is made using a different technological process. Can it be imagined that the primary reason for the imitation is not the process but the product in this case? The potential depends on the degree to which the results of an innovation are visible to users (Rogers 1983). The use of rotation, especially when rotational energy significantly contributes to the forming, can result in characteristic surface morphology and texture, symmetry of vessels as well as specific character of orbital decorative elements like raised bars, ribs, grooves and incisions that are difficult to imitate using alternative hand-building techniques. The visual performance is not an inevitable consequence of the use of the technique. The characteristic visual appearance is achieved if the potter exploits the intrinsic performances of the technique and allows the effect resulting from the technique to be manifested in the final product. This means that the potter (a) creates shapes and features in accordance with rotation around a vertical axis, (b) does not imitate the effects of another technique or (c) does not use a secondary forming technique based on another principle.

The similar visual performance is also theoretically achievable by using alternative techniques. However, the performance of these techniques related to the task is different. For example, the symmetry of the shape or the regular orbital decorative features are a consequence of using the rotation of the object around a vertical axis. An asymmetrical shape means an imperfection or the intentional overcoming of the constraints of the technique. On the other hand, *e.g.*, for coiling, the symmetry is an external concept that does not emerge from the character of the technique. Consequently, preferences in such visual performances create a strong selective environment that favours the application of rotational energy in forming over alternative hand-building techniques.

By postulating the characteristic visual performance, we do not imply that wheel-made pottery is aesthetically or functionally superior to hand-built pottery. Perfection is evaluated on the basis of cultural and individual criteria. Visual performances do not represent inherent objective qualities on the basis of which users make their choices. These choices are based on the semantics of the visual features which are communicated in social negotiations and coded by a culture. The distinctive visual performance can constitute a new cultural "morpheme" which affects the "grammar" of social interactions and thus consumer behavioural patterns.

The distinctive visual appearance can be achieved by different ways of using rotational energy—different innovations based on the same invention—with different process performances (time efficiency, skills or tool requirements). The demand for such a visual performance stimulates learning of adequate technological gestures leading to adoption or development of techniques facilitating the use of these gestures. If the visual performance of products defines the cultural fitness of the novel technology, then the fitness of the manufacturing process can be determined by multiple adaptive environments, in which case individual learning can cause a divergence of different locally adaptive states (*cf.* Mesoudi and O'Brien 2008a, b).

The discussed aspect of visual performance suggests that the significance of performance characteristics for the adoption of a new cultural variant is, among other factors, determined by its cultural and social context (the role of the cultural and social context in innovation process is frequently emphasised in the anthropological literature, *e.g.*, Haudricourt 1987; van der Leeuw and Torrence 1989; Gosselain 1992, 1998, Lemonnier 1992, 1993; Pfaffenberger 1992; Dobres and Hoffman 1994; Stark 1998; Dobres 2000; Sillar and Tite 2000; Skibo and Schiffer 2008). Consequently, cultural fitness is not an inherent quality of an object or process. It is constructed through the communication of performances within a society. The contextuality of cultural fitness is probably most markedly reflected in the dichotomy between status-defining (prestige) goods and common goods (*e.g.*, Weiner 1992; Helms 1993). The cultural fitness of manufacturing methods producing common (or utilitarian) goods is usually related to the efficiency and minimisation of the risks associated with the production. In contrast, the production methods of socially charged goods emphasises their extraordinariness by employing costly materials and techniques: *e.g.*, the use of complex technological processes, processes that require an extensive labour force, a long time to complete the task or skills attainable only by long apprenticeship (Earle 1981; Miller 1982; Brumfiel and Earle 1987; Peregrine 1991; Hayden 1995, 1998).

Moreover, the social context affects the structure of learning networks, incentives to imitate the behaviour of particular individuals or the means of influencing others. Individuals play specific roles in the innovation process. The persons who actually introduce an innovation (*change agents*) are often strangers to the community involved. They are not necessarily respected or well integrated into the local social system. However, if the innovation is to be adopted, then it has to be promoted by individuals who are models worth imitating—*leaders of opinion*. They exercise their influence in an informal way, have a high status, have frequent intergroup contact and can usually cope well with uncertainty, as they control adequate resources to absorb possible losses incurred due to adoption of the novelty (Rogers and Shoemaker 1971; Rogers 1983; Bargatzky 1989). The resources of influential individuals (or knowledge and skills if they are also the craftsmen) allow them to control production of goods in the case of discontinuous innovations with high skill demands. In such situations, the innovations tend to emerge, develop and expand in closed systems, *i.e.* they are transmitted in restricted learning networks that prevent exchange of information with other networks (Roux 2010). Such restrictions are usually motivated by the economic or social profit of those who control the production.

The following analysis of the Iron Age pottery in a selected region of Eastern Bohemia was performed to explore links between the social context and the technological innovation. For this purpose, the analysis is focused on two topics: (a) process and product performances and (b) the character of networks in which the new technique was transmitted.

(a) We pointed out that there are different means of application of rotational energy for pottery forming, implying different performance characteristics of the respective techniques. To discuss the possible reasons why a new technique was chosen by particular potters, we will determine which performances could influence their choices, *i.e.* we will explore how rotational energy was employed in the pottery-forming sequence.

(b) Three archaeologically traceable phenomena can be considered in investigating the character of networks in which a new technique was transmitted: (1) the number of workshops producing wheel-made pottery in the region and the intensity of their production, (2) the degree of stylistic and technological divergence between the manufacture of wheel-made pottery and the rest of the pottery production and (3) the distribution of wheel-made pottery. Due to the character of archaeological evidence from the La Tène period in the area of Central Europe (especially the lack of direct evidence for pottery workshops and inability to associate the distribution of wheel-made pottery with its use by specific social groups), we focus especially on analysis of the two first phenomena by estimation of the diversity of clay sources for production of wheel-made pottery and by analysis of the correspondence between the forming techniques, style and practices used in other phases of pottery manufacture (specifically selection of raw materials and pottery firing).

The results of the analysis will be integrated in the discussion, seeking links between the performance characteristics of pottery-forming practices and their products and the technological and provenance diversity of pottery production on the background of a changing social context. The significance of the distribution of wheel-made pottery in the given context for understanding the innovation process will also be discussed.

The Chrudim Region and Its Late Hallstatt and La Tène Settlement

The selected region is situated in the north-eastern part of the La Tène settlement of Bohemia (Fig. 2a) near the confluence of the Elbe and Chrudimka Rivers—for the sake of simplicity, the area is hereinafter referred to as the Chrudim region (Waldhauser 2001; Venclová 2008a). Geomorphologically, it belongs to the Chrudim basin and the northernmost part to the Pardubice basin (subprovince of the Bohemian Table) characterised by flat uplands in the river basins. The sole but very important site—České Lhotice oppidum—is located in the Sečská vrchovina highland (part of the Železné hory (Iron Mts.) subprovince of the Bohemian-Moravian Upland) which constitutes the south-western margin of the region (Fig. 2b; Demek and Mackovčin 2006).

Settlement was continuous during the La Tène period (Mangel 1998). So far, infrequent evidence for La Tène A (480/460–390/375 BC)[2] settlements indicates that they were usually located in the areas occupied during the previous period (Hallstatt D2–3; 540/530–480/460 BC), which is analogous to the situation in at least some other regions of the Czech Republic (Waldhauser 1993). Flat-grave cemeteries are the main source of evidence for settlements in Central Europe in the subsequent fourth–third century BC. The Chrudim region is no exception. Most of the archaeological evidence reliably dated to this period—La Tène B–C1 (390/375–190/175 BC)—consists in a few smaller inhumation cemeteries and isolated graves (Mangel *et al.* 2013). Settlements have so far not been identified and/or this period is chronologically not differentiated

[2] The relative chronology and absolute dating is based on the last synthesis of Bohemian prehistory (Venclová 2008b; Venclová 2008a).

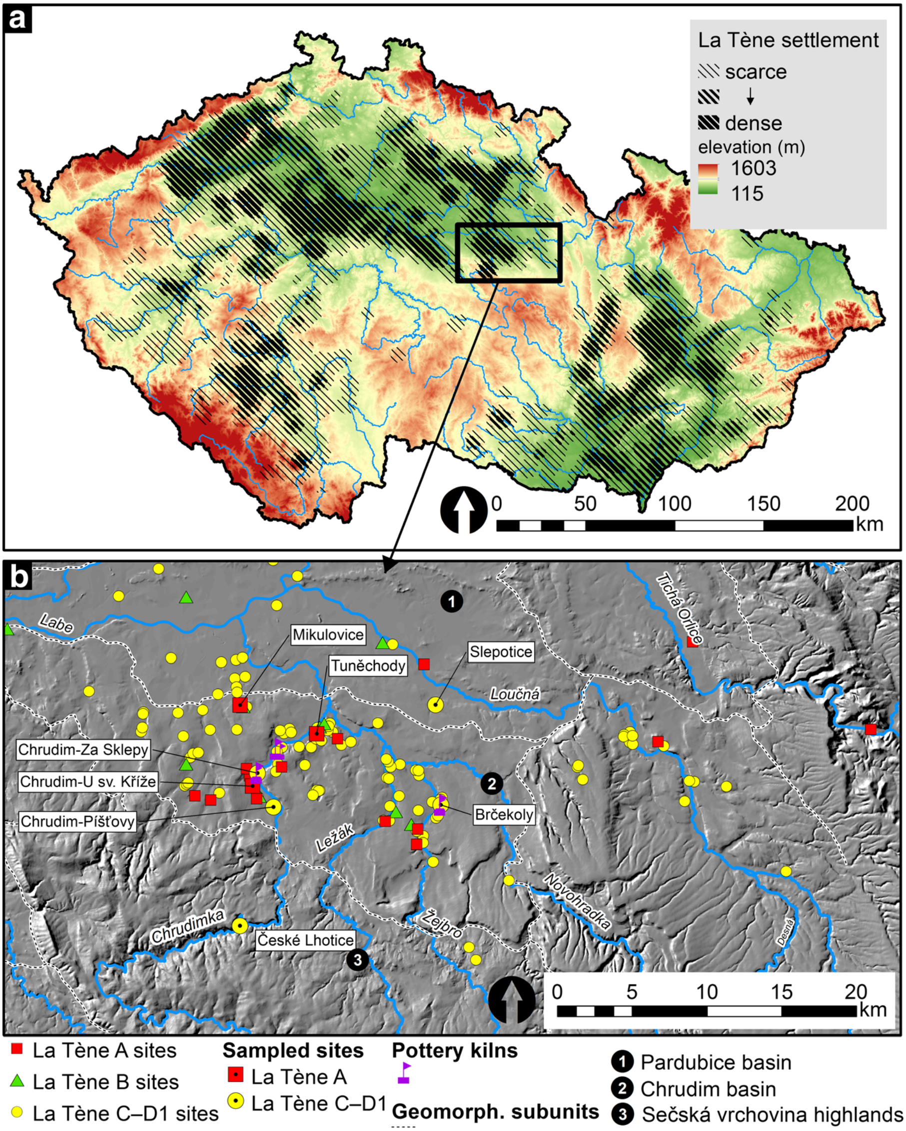

Fig. 2 **a** La Tène settlement in the Czech Republic (according to the materials prepared by B. Danielisová) with indication of the region selected for the analysis. **b** The selected region with the La Tène settlement and sampled archaeological sites

from the latter phases of the La Tène period on the basis of current evidence for settlements. A significant increase in the number of settlements during the La Tène C–D1 period (260/250–50/30 BC) has been documented. Once again, this was a general trend in a wider area of the Czech Republic (*e.g.*, Waldhauser 1976). The České Lhotice oppidum, the only eastern Bohemian site of this type (Danielisová 2010), is an exceptional site dating back to this period. The location of the site in the Železné hory (Iron Mts.) points to two probable reasons for establishment of the oppidum: (a) the exploitation of rich mineral resources in the area and (b) its mediating role in contacts between Bohemia and Moravia.

Materials and Methods of Technological and Provenance Analysis

Due to the scarcity of direct evidence for the means of pottery production, the products themselves are of key importance for studying the technological processes employed. The available archaeological data allow us to study similarities and differences in relevant technological traits and their correspondences within and between pottery assemblages from archaeological sites as spatially restricted samples of ancient pottery production. Estimation of the regional variability in forming techniques and related technological attributes is based on sampling of the largest pottery assemblages from the region (Fig. 2b). The pottery from selected sites was categorised according to the proportions of the main types of inclusions observable on the edges of the sherds and attributes of surface treatment and pottery shapes. Combinations of these categories were sampled for technological, petrographic and compositional analysis.

The sampling covered two of the three main phases of the studied period. The settlement at Tuněchody is the most important for understanding the introduction of the potter's wheel at the beginning of the La Tène period in the region. Five excavation seasons between 1997 and 2009 yielded more than 20,000 sherds: the majority of which can be dated to the Hallstatt D2–La Tène A periods (Tichý *et al.* 2006, 2007). Four settlement phases can be identified. Two other La Tène A settlements were sampled: Chrudim-U sv. Kříže (Čtverák *et al.* 2007) and Mikulovice (Sedláček 2007; Sedláček and Sankot 2013).

The rest of the sampled sites represent La Tène C–D1 settlements. The selection also includes the České Lhotice oppidum (Danielisová 2010) and two sites with remains of pottery kilns: Brčekoly (Princ and Skružný 1977; Thér *et al.* 2014) and Chrudim-Za Sklepy (Thér *et al.* 2014).

The lack of undisputed La Tène B–C1 assemblages from the region made suitable sampling of this period impossible. A small number of reconstructed vessels from cemeteries (Mangel 1998, 2009, 2011) constitute the only pottery reliably dated to the period. It is practically impossible to obtain permission for destructive analysis of these vessels. Thus, we can follow the changes in time by comparing the earlier (La Tène A) and later (La Tène C–D1) phases of the La Tène period without the possibility of tracing the trajectories of the transformation of pottery production between the La Tène A and the La Tène C–D1 periods (Table 1).

Analysis of Pottery-Forming Techniques

In relation to the use of rotation to form pottery, we can trace the technological idea (initial general invention) more readily than the innovations. Neither the potter's wheel nor the manner of its use can be directly observed in many archaeological contexts. Traction marks on pottery surface undoubtedly indicate adoption of the idea of the use of rotational movement for forming (in many cases, we are not even able to reliably decide what was rotating—the vessel or the potter's hands) while the details of how the idea was put into practice can remain uncertain. The visual diagnostic traces are not

Table 1 Sampling of the late Hallstatt and La Tène pottery assemblages from the Chrudim region

Chronology	Absolute dating	Class		Brčekoly	České Lhotice	Chrudim-U sv. Kříže	Chrudim-Píšťovy	Chrudim-Za Sklepy	Mikulovice	Slepotice	Tuněchody	Sum
Ha D2–3	540/530–480/460 BC	Hand-built pottery	Mac. obser.								4098	4098
			Perp. sections								104	104
			Tang. sections								6	6
			ICP-MS								40	40
LT A	480/460–390/375 BC	Hand-built pottery	Mac. obser.			36			247		1992	2275
			Perp. sections			2			0		51	53
			Tang. sections			0			0		5	5
			ICP-MS			2			0		14	16
		Fine wheel-made pottery	Mac. obser.			11			21		225	257
			Perp. sections			2			6		35	43
			Tang. sections			0			0		13	13
			ICP-MS			4			8		40	52
LT B	390/375–260/250 BC											
LT C–D1	260/250–50/30 BC	Hand-built pottery	Mac. obser.	103	6587		146	141		1328		8305
			Perp. sections	4	18		3	0		32		57
			Tang. sections	0	2		0	0		3		5
			ICP-MS	0	0		0	0		0		0
		Coarse wheel-made pottery	Mac. obser.	40	668		23	72		388		1191
			Perp. sections	11	23		3	5		26		68
			Tang. sections	5	3		0	2		5		15
			ICP-MS	8	18		5	3		11		45
		Fine wheel-made pottery	Mac. obser.	20	2389		54	31		332		2826

Table 1 (continued)

Chronology	Absolute dating	Class	Brčekoly	České Lhotice	Chrudim- U sv. Kříže	Chrudim-Píšťovy	Chrudim-Za Sklepy	Mikulovice	Slepotice	Tuněchody	Sum
		Perp. sections	4	20		3	6		26		59
		Tang. sections	0	9		0	0		4		13
		ICP-MS	5	15		4	4		31		59

reliable attributes for identifying the entire forming sequence of wheel-made pottery in this case. The general problems of interpretation of the visual attributes are complicated by the specific properties of the analysed material: fragmentary state of the pottery and careful surface treatment of wheel-made pottery. Macroscopic diagnostic features can be observed only exceptionally. Consequently, identification of the forming sequence is based on analysis of the orientation of inclusions and voids in thin sections. The application of physical force to the plastic clay during forming is the main factor affecting the alignment of the components of ceramic materials. The alignment is characteristic of each forming method, although some orientation patterns might result from more than one fabrication process (for the overview of the assumption for particular techniques, see Rye 1981; Carr 1990; Courty and Roux 1995; Whitbread 1996; Livingstone Smith 2007; Berg 2008). The alignment of inclusions is usually characterised by qualitative categories or ordinal scales. One of the authors recently developed a methodology allowing quantitative analysis of the orientation. The orientation characteristics are measured on standard vertical thin sections perpendicular to the vessel wall and sections tangential to the vessel wall cut through a core zone of the wall—tangential sections (for a detailed description of the methodology, see Thér 2016).

The estimated orientation variability for basic forming techniques and their combinations is based on already published pilot experimental assemblage (Thér 2016) supplemented by a second series of experimental samples focused on the application of rotation during forming. Four potters participated on the replication of the forming techniques, and the current dataset comprises 133 perpendicular sections and 74 tangential sections. The object orientation is represented by two basic descriptors: (a) mean direction—average orientation of objects and (b) circular standard deviation (CSD)—the dispersion of the values from the average (Fisher 1993; Mardia and Jupp 2000). The alignment of objects in a core area of a section is the most important parameter for the perpendicular sections in the current state of research. The core area is defined as the zone in the centre of the section with width measuring half of the average thickness of the vessel wall. The alignment is represented by CSD (Fig. 3). For the tangential section, the raw data are plotted in a polar coordinate system (Fig. 4). Each point in the diagram is determined by an angle from a reference direction which represents the mean direction of the objects of the given sample and the distance from the centre of the circle which represents CSD. The points more distant from the centre of the circle have less aligned microstructures. The calculated orientations are an axial type of data. Axial data consist of an undirected line—either end of the line could be taken as the direction; therefore, the data are represented by both possible directions, *i.e.* each sample is plotted by a pair of points.

Comparison of the CSD of the orientation (Fig. 3) shows differences between perpendicular pressure techniques (pinching) and coiling. However, coiling is a large family of techniques differing in degree of transformation of the lump of clay into the coil and the transformation of coils during building of the vessel wall. Two extreme variants in terms of coil transformation during building of the vessel wall are included in the coiling group. The degree of transformation clearly affects the alignment (see Thér 2016 where the variants are analysed separately). Pinching can also cause variable alignment reaching up to 40°. The CSD of objects in perpendicular sections is a poor predictor for wheel throwing.

Wheel throwing cannot be distinguished from pinching, and only values higher than 50° indicate alignment that cannot be attributed to the technique. Composite techniques further blur the differences. Coiling can still be recognised when wheel finishing is employed, but wheel shaping causes a substantial decrease in the CSD values in the core area and the primary technique cannot be clearly identified. The same trend applies when rotation is combined with pinching as a primary forming technique (Fig. 3: PWF, PWS).

Contrary to the perpendicular sections, all the included primary forming techniques, pinching, coiling and wheel throwing, can be clearly distinguished based on the orientation and alignment in tangential sections (Fig. 4). The coiling samples form two subgroups: well aligned (with CSD oscillating around 20°) and poorly aligned (with CSD more than 30° and deviating from typical horizontal alignment). Orientation in tangential sections for samples from vessels formed using composite techniques reflects the structures imposed by primary forming techniques and shift towards the structure characteristic for wheel throwing that depends on the contribution of rotational energy in forming. Horizontal alignment in tangential sections typical for coiling can be seen in wheel-finished samples. Wheel-shaped samples exhibit alteration of angles towards the mean direction typical for wheel throwing (Fig. 4).

Based on the current experimental collection, differences between techniques using compressive deformation by discontinuous pressure (here represented by pinching) and rolling in combination with compression (coiling) can be observed on both of the sections. However, only the alignment in the tangential section preserves the distinctive character of the primary forming technique if a different secondary forming technique transforming the microstructure of the vessel wall is used. The tangential sections are also crucial in assessing the contribution of the use of rotational energy in the particular forming sequence. Unfortunately, tangential sections require more careful selection of samples and their acquisition has a significantly more destructive impact, which is problematic considering the relatively scarce occurrence of wheel-made pottery in the studied assemblages and its fragmentary state. Thus, tangential sections only supplemented the basic sampling of the La Tène from the Chrudim region (384 perpendicular vs. 57 tangential sections; Table 1).

Geochemical and Petrographic Analyses

Geochemical Analysis The analysis was designed to differentiate compositional groups independently of the technological processes/intentions of the potter. The emphasis was placed on wheel-made pottery. The elements, whose amount is potentially affected by the formation processes; the ratio of the basic aplastic components of the ceramic materials and the technological process (Cogswell *et al.* 1996; Buxeda i Garrigós 1999; Buxeda i Garrigós *et al.* 2002; Schwedt *et al.* 2004; Mommsen and Sjöberg 2007; Schwedt and Mommsen 2007; Tite 2008) were excluded from the statistical analysis. The result is a group of 38 elements.[3] The analysis was performed by Acme Analytical Laboratories Ltd. A 0.25-g split was heated in HNO_3-$HClO_4$-HF to fuming and reduced to dryness. The residue was dissolved in HCl. The solutions

[3] Be, Bi, Cd, Ce, Co, Cr, Cu, Dy, Er, Fe, Ga, Gd, Hf, Ho, Li, Lu, Mn, Mo, Nb, Nd, Ni, Pb, Pr, Sb, Sc, Sn, Ta, Tb, Th, Ti, Tm, U, V, W, Y, Yb, Zn, Zr.

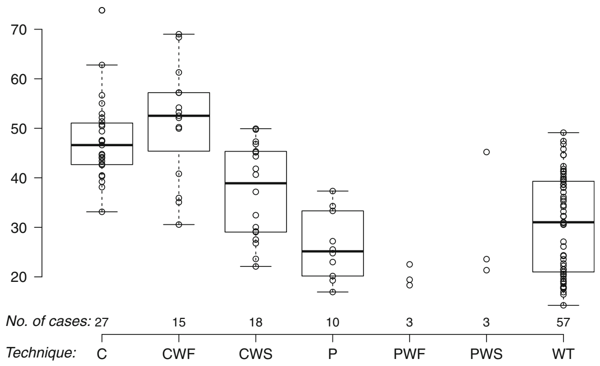

Fig. 3 Circular standard deviation of objects in the core area of perpendicular sections taken from experimental vessels. *C* coiling, *CWF* coiling in combination with wheel finishing, *CWS* coiling in combination with wheel shaping, *P* pinching, *PWF* pinching in combination with wheel finishing, *PWS* pinching in combination with wheel shaping, *WT* wheel throwing

were analysed by ICP-MS. The data were log-ratio transformed in accordance with the principles of Aitchison geometry (Aitchison 1986) using the CoDaPack software (Comas-Cufí and Thió-Henestrosa 2011). A principal component analysis was performed to determine the main compositional groups of the ceramics. The analysis was complemented by identification of outliers on the basis of the Mahalanobis distance based on the minimum covariance determinant (MCD) of the medium distance of the value and variability of the data (Rousseeuw 1985). This method was used for the identification of measurements that are not part of the distribution of the given data. The identified outliers were excluded from the principal component analysis. The

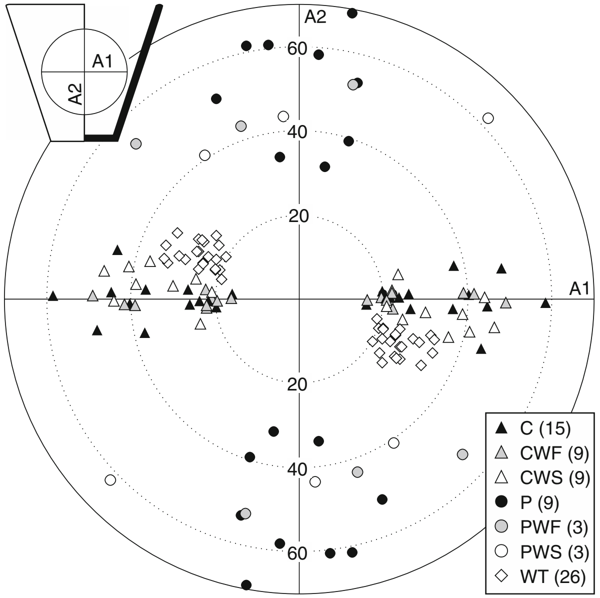

Fig. 4 Polar diagram of the mean direction in combination with circular standard deviation of objects in tangential sections taken from experimental vessels (for the legend, see Fig. 3, the *numbers in the parentheses* indicate the number of samples)

analysis was undertaken using the mvoutlier R package (Filzmoser *et al.* 2005, 2012; Filzmoser and Hron 2008).

Petrographic Analysis Provenance analysis based on chemical composition was supplemented by petrographic analysis of thin sections. The origin of the raw material used for the pottery production was estimated based on the mineralogical and petrographic composition of the ceramic materials and comparison with the geological situation in the nearest surroundings of the studied sites (*e.g.*, Shepard 1956; Velde and Druc 1999; Reedy 2008; Quinn 2013). Petrographic observations were also used to estimate the firing conditions. The estimation was based on the observed mineralogical changes in a clayish matrix (isotropisation of the matrix) and in non-plastic inclusions (*e.g.*, Shepard 1956; Maggetti 1982; Rice 1987; Velde and Druc 1999; Ionescu and Ghergari 2002; Grapes 2006; Reedy 2008; Quinn 2013).

Hallstatt D2–La Tène D1 Pottery from the Chrudim Region[4]

Overview of Shapes and Decoration (Fig. 5)

Hallstatt D2–3 For the period preceding the introduction of wheel-made pottery (Hallstatt D2–3), restricted bowls with simple contours and in-turned rims (Fig. 5: 1), unrestricted carinated bowls (Fig. 5: 2) and cups (Fig. 5: 3, 4) are the characteristic shapes of hand-built[5] fine ware. Graphite was generally used to decorate the vessels with polished geometric ornaments (Fig. 6a: 1–3 and 6, 7). The repertoire of lower shapes of coarser pottery is limited to restricted bowls with simple contours and in-turned rims (Fig. 5: 5). The common taller shapes are represented by barrels (simple contoured restricted vessels, Fig. 5: 8) and pots, predominantly with inflected contours (Fig. 5: 6, 7), and sometimes decorated by various forms of raised bands or lines of finger tipping and jars[6] (Fig. 5: 9, 10). By the end of this period and also during the subsequent La Tène A period, the decoration and formal details of coarse pottery had changed. Pots mostly had shapes with composite contours and short necks (Fig. 5: 15–17). Horizontally flattened rims and carefully formed raised bands are typical, and a vessel body covered by nail impressions was a new feature.

La Tène A The most significant change in pottery technology in the La Tène A period was the introduction of wheel-made pottery. The most frequent forms of this pottery were restricted bowls (with composite or inflected contours, Fig. 5: 11, 12). Some of them were decorated using stamps and compasses, usually on the interior (Fig. 6b). A

[4] Characterisation of the pottery shapes is based on the descriptive system of Shepard (1956). Classification of the shapes of the Hallstatt D2–3 and La Tène A pottery is used according to Dreslerová and Beech (1995) and Chytráček and Bernat (2000) and of the La Tène B–D pottery according to Venclová (1998).

[5] The term hand-built pottery is used for all the pottery which does not exhibit visual evidence for the use of rotational movement during forming.

[6] The more general term jar is used instead of amphora or amphora-like vessel commonly used in classifications of pottery shapes from this period (Dreslerová and Beech 1995; Chytráček and Bernat 2000).

bottle (Figs. 5: 13, 6b: 4) was the basic form of tall shapes in this pottery category in this period. Bottles were sometimes decorated with horizontal grooves and raised bands (Mangel *et al.* 2013). The introduction of wheel-made pottery caused a dramatic decrease in the proportion of hand-built fine ware (from more than 10 to approx. 2%). No changes can be observed in the forms and decorations of hand-built coarse pottery compared to the previous period.

La Tène C–D1 Restricted bowls with inflected contours (Fig. 5: 20) are the dominant form in the repertoire of wheel-made fine pottery dated to the La Tène C–D1 period, supplemented by restricted bowls with in-turned rims and simple or composite contours (Fig. 5: 21). Different variants of pots (Fig. 5: 22, 23), vases (Fig. 5: 24), situlas and beakers (Fig. 5: 25) can be seen among taller shapes. Raised and incised decoration most frequently occurs on fine ware. Bowls can be decorated with concentric smoothed or polished straight or wavy lines and garlands. Similar decoration was executed on tall shapes, but located on the exterior of the neck and shoulders of the vessel. Only a few examples from the region exhibit the use of so-called fine combing (*cf.* Trebsche 2003), painting (Mangel *et al.* 2013) and stamped decoration (Danielisová 2010; Mangel 2011). The use of rotation during forming is apparent not only on fine ware but also on coarser pottery. The spectrum of shapes of wheel-made coarse pottery is similar to hand-built pottery. It is represented especially by pots (Fig. 5: 29, 30, 35, 36), restricted bowls with in-turned rims (Fig. 5: 26–28, 34) and storage jars (Fig. 5: 32, 33, 37, 38). Horizontal ribs, flutes, grooves and smoothed or polished decorations can also be seen on coarse pottery, but application of combing, black coatings and surfaces modified by scraping is more typical.

Ceramic Materials (Fig. 7)

Hallstatt D2–3 For the Hallstatt D2–La Tène A period, the picture of the variability of the ceramic paste recipes is based on analysis of the pottery from Tuněchody. In the first settlement phase (Hallstatt D2–3), ceramic materials tempered with grog dominated production of all the pottery forms (approx. 80%). In more than half of the cases, the grog contains fragments of pottery tempered with graphite, but the proportion of graphite is usually very low (up to 5%). This material was used for the production of pots and coarse bowls. Exceptional cases of pots tempered with graphite from the Hallstatt D2–3 contexts can be found.

In the second settlement phase (Hallstatt D3/La Tène A), grog-tempered pottery still predominates. The main change was a significant decrease in non-graphite grog-tempered pottery. Graphite either directly or indirectly (via grog temper) added to the clay becomes a standard ingredient of locally produced pottery. Direct graphite tempering is documented only for pots (25% of pots). The dominant fabrics are supplemented by materials containing crystals of micas with size over 1 mm.

La Tène A A continual change in the materials used for coarse ware can be observed in the third settlement phase (earlier phase of La Tène A). Almost 80% of the pots were tempered with graphite, while the rest had grog

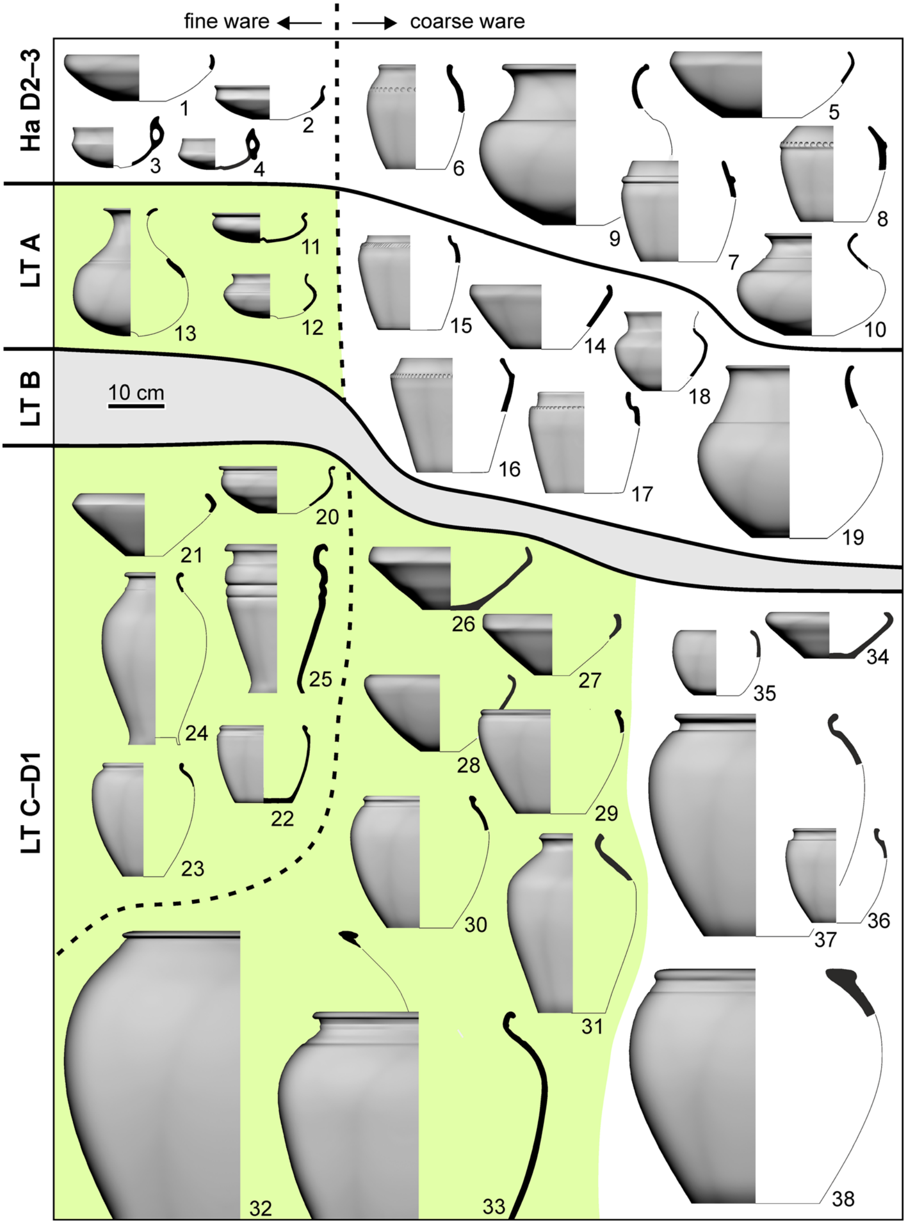

Fig. 5 Basic shapes of the late Hallstatt and the La Tène pottery in the Chrudim region. The *shaded zone* indicates wheel-made pottery

containing fragments of graphite-tempered pottery. All the sampled coarse bowls and jars were tempered with grog: 80% of them contain fragments of graphite-tempered pottery. The new tradition of fine wheel-made pottery represents a clear discontinuity in terms of paste preparation. Only ceramic pastes without grog were used for production of this pottery. The dominant material

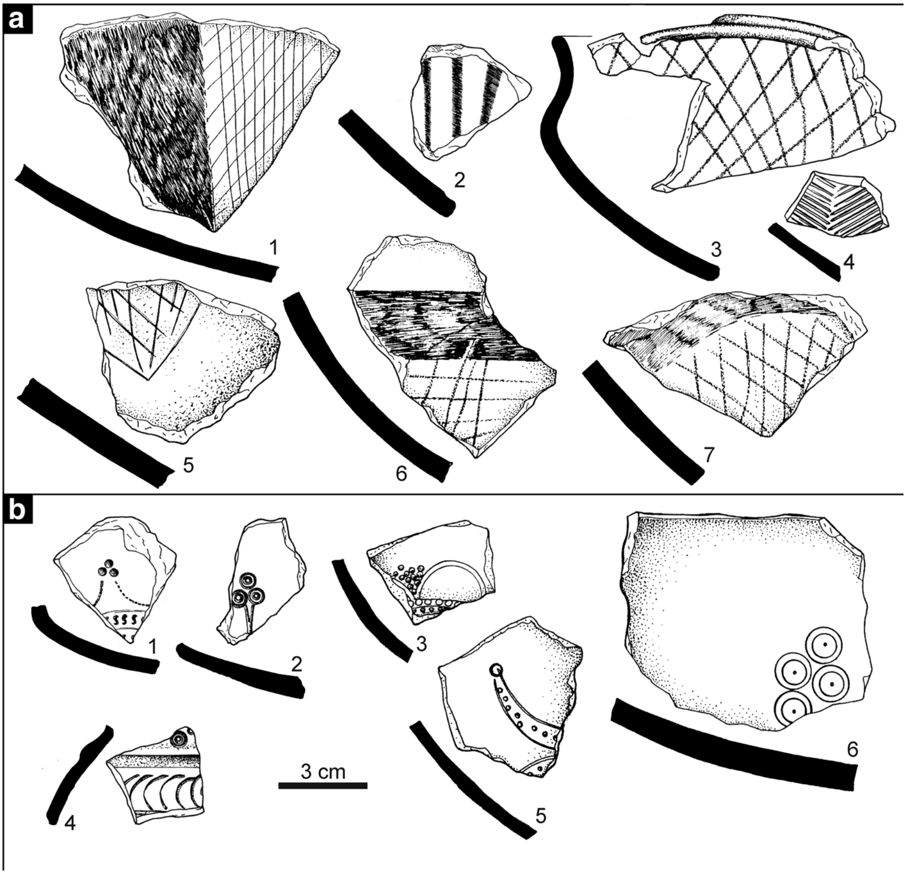

Fig. 6 Comparison of decorative features observed on Hallstatt D2–La Tène A hand-built fine ware (**a**) and La Tène A wheel-made pottery (**b**) from Tuněchody (drawings by V. Drnovský)

was highly standardised and tempered with 20% well-sorted sand (fraction usually to 0.5 mm). Materials containing mica crystals over 1 mm in size disappeared along with hand-built fine ware.

No significant changes in selection and preparation of the materials for coarse ware can be seen in the fourth settlement phase (latter phase of La Tène A). Wheel-made pottery underwent a substantial change in fabric texture. Most of this pottery was made from fine-grained ceramic materials.

La Tène C–D1 Fine-grained fabrics were standard for wheel-made fine ware in the latter phases of the La Tène period in the region. During this period, three basic types of tempering materials were used in the production of coarse pottery. Materials tempered with fluvial sands (50–70% of coarse pottery[7]) were the most abundant in the common settlements in the Chrudim region. The inclusions are usually better sorted, and their proportion is greater than for Hallstatt D2–La Tène A coarse pottery (20–30 vs. up to

[7] The intervals account for the differences in the individual sampled sites.

10%). Graphite-tempered pottery occurs in rather small proportions (5–15% of coarse pottery). The graphite temper was added in finer (up to 1 mm) or coarser (up to 4 mm) fractions. In both cases, the proportion of graphite in the fabric is very high (30–40%). Apart from these typical fabrics, materials with a proportion of graphite up to 10% can also be found.

Unlike in the earlier periods, the application of rotation during forming can also be seen on coarse ware in the La Tène C–D1 period (coarse ware represents more than 50% of wheel-made pottery). The specific tempering materials, mica and graphite, are more frequently associated with the production of skill-demanding vessel forms (large storage jars, 20–30% of production compared to approx. 5% of sand-tempered production) or with pottery meeting increased demand on functional properties (especially graphite-tempered materials that were preferred for pots). Grog completely disappeared as tempering material.

Forming Techniques

The interpretation of forming techniques is based mainly on quantitative analysis of the orientation of components of the clay body supplemented by macroscopic observations. The orientation and alignment of objects in a core area of a perpendicular section (Fig. 8) and in a tangential section (Fig. 9) are presented in the same manner as the results of analysis of the experimental collection (Figs. 3 and 4).

In the light of the analysis of the experimental collection, we can estimate the forming techniques for different categories of the sampled La Tène pottery. The hand-built pottery from the Hallstatt D2–3 and the La Tène A periods reaches higher CSD values in the core areas of perpendicular sections (Fig. 8) compared to the La Tène C–D1 hand-built pottery. However, there is significant overlap between the distributions and the variance suggests the use of combined hand-built techniques or a diversity of forming techniques within the groups. The highest CSD values, corresponding to the use of a simple coiling technique without subsequent significant

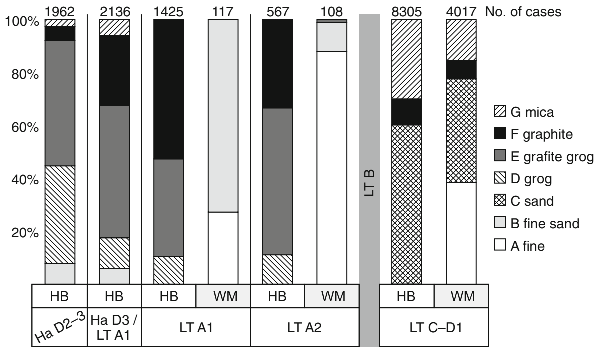

Fig. 7 Proportion of basic pottery paste recipes of hand-built and wheel-made pottery in the sampled phases of the La Tène period. *A* fine-grained material; *B* material tempered with sand up to the medium fraction (up to 0.5 mm); *C*—material tempered with sand of the coarse to very coarse fraction (0.5–2 mm, exceptionally more than 2 mm); *D*—material tempered with grog; *E*—material tempered with grog containing graphite, usually together with non-graphite grog; *F*—material tempered with graphite, in Hallstatt D2–La Tène A pottery this can be accompanied by grog; *G*—material tempered with micaceous rocks

transformation of the coils, are characteristic for some of the pottery of non-regional origin[8] in Tuněchody (Fig. 8).

To gain a clearer picture, it is necessary to focus on the tangential sections. The high CSD values of the Hallstatt D2–3 and the La Tène A local hand-built pottery (Fig. 9) undoubtedly point to the application of compression perpendicular to the wall as the primary force used for forming the vessel or segments from which the vessel was assembled in all the sampled cases. The rare, macroscopically observable features (Fig. 10a) point to the use of slabs joined at horizontally oriented edges. Poor alignment in the perpendicular sections can be explained by the use of small bulks of clay slightly formed by pinching into slabs.

On the other hand, the horizontal orientation of particles in the tangential sections typical for La Tène C–D1 coarse hand-built pottery (Fig. 9) in combination with moderate CSD values in core areas of perpendicular sections (Fig. 8) is most consistent with the use of coiling as the primary forming technique, but with coils substantially reshaped by other hand-building techniques (drawing, pinching or beating). Coil joins are also documented macroscopically (Fig. 10b).

The average directions of inclusions and voids in tangential sections of the La Tène A wheel-made pottery show that a fair number of the samples significantly deviate from the horizontal plane but do not reach the parameters characteristic for wheel-thrown vessels (Fig. 9). This general trend points to a composite technique with coiling as the primary forming technique. The mean direction of the majority of the samples reflects considerable use of the rotational device as the secondary forming technique (wheel shaping). The residues of coil joins, which can be very occasionally observed (Fig. 11), are in accordance with the results of the orientation analysis.

Most of the sampled fine bowls, vases and situlae dated to the La Tène C–D1 period fall within the confidence interval for wheel-thrown pottery, but the results indicate that wheel shaping was still used in the manufacture of fine ware. The use of rotation during the forming of coarse wheel-made pottery had a minimal effect in transformation of the fabric microstructure (wheel finishing). Horizontal orientation is preserved (Fig. 9), documenting coiling as the primary forming technique. Wheel-made pottery dated from La Tène C onwards show the use of reverse rotation. While La Tène A pottery was rotated clockwise, latter pottery was rotated anticlockwise.

Firing Conditions

The observed petrographic phenomena indicate that, in general, the firing temperatures did not exceeded 800 °C. An anisotropic character of the matrix is characteristic for most of the samples from all the sampled sites except for graphitic fabrics, where the optical character of the matrix is affected by the presence of fine-grained graphite. Samples containing calcite exhibit the presence of its thermally unaltered state (micritic as well as sparitic). The matrix is mostly coloured reddish or brownish due to the presence of submicroscopic hematite. The presence of charred organic residues (mainly plant residues) is also characteristic for all the local groups of pottery. No further mineralogical changes in the matrix or in non-plastic inclusions were observed.

[8] Based on compositional and petrographic analysis, all the samples with CSD more than 60° are of non-regional origin.

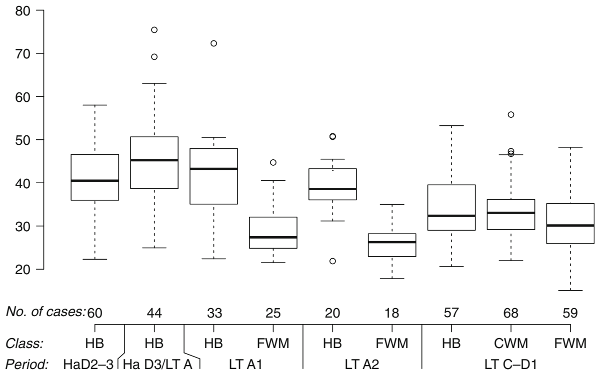

Fig. 8 Comparison of circular standard deviations of the orientation of inclusions and voids in the core zones of perpendicular sections of the La Tène pottery from the Chrudim region. Material/forming groups: *HB* hand-built pottery, *FWM* fine wheel-made pottery, *CWM* coarse wheel-made pottery

Isotropic character of the matrix with completely or partly decomposed calcite, features that indicated firing temperatures above 800 °C, was found in only exceptional cases.

In addition to the temperature, also the atmosphere, *i.e.* the chemical composition of the flue gases, is an important parameter in pottery firing. One of the effects of the combination of a particular temperature and atmosphere on ceramics is their colour. Colour patterns on a section of the vessel wall seem to be most informative for the employed firing process (*e.g.*, Rye 1981; Rice 1987; Gibson and Woods 1997; Haith 1997; McDonnell 2001; Perlès and Monthel 2001; Saunders and Hays 2004; Szakmány and Starnini 2007). However, the assumption that colour patterns can be associated with a particular firing process is not free of difficulties (*e.g.*, Rice 1987; Shimada *et al.* 2003; Thér 2012). Without entering into a complicated debate on the interpretation of firing procedures based on colour patterns, we can simply assume that a significant difference in the proportion of colour patterns reflects a difference in the firing procedures. This assumption is sufficient to answer the particular questions arising in this analysis.

The relationship between colour zones in terms of lightness and chroma is the most important for the classification of basic colour patterns. We reduced classification of the variability of the colours to dark and light layers. To prevent the masking of significant differences by recording marginal colour differences, the minimum lightness difference was set at 3 units on the value dimension or 3 units on the chroma dimension of the Munsell colour system. If no layering was observed, then, the dark colour corresponds to colours up to value 6 and chroma 4. The basic groups of colour patterns are (a) homogenous colour, (b) symmetrical parallel colour layering, (c) asymmetrical parallel colour layering and (d) asymmetrical non-parallel colour layering (Fig. 12).

The preference for pottery fired under reducing conditions is characteristic for all the Iron Age pottery in the region. The lighter colours can be seen as imperfections in the homogeneity of the firing or as a consequence of postfiring alteration of the ceramics randomly affecting all the pottery except the vessels used for thermal processes. Consequently, pots as a form of pottery hypothetically used for cooking were excluded from the analysis. Relative comparison of these imperfections can point to differences

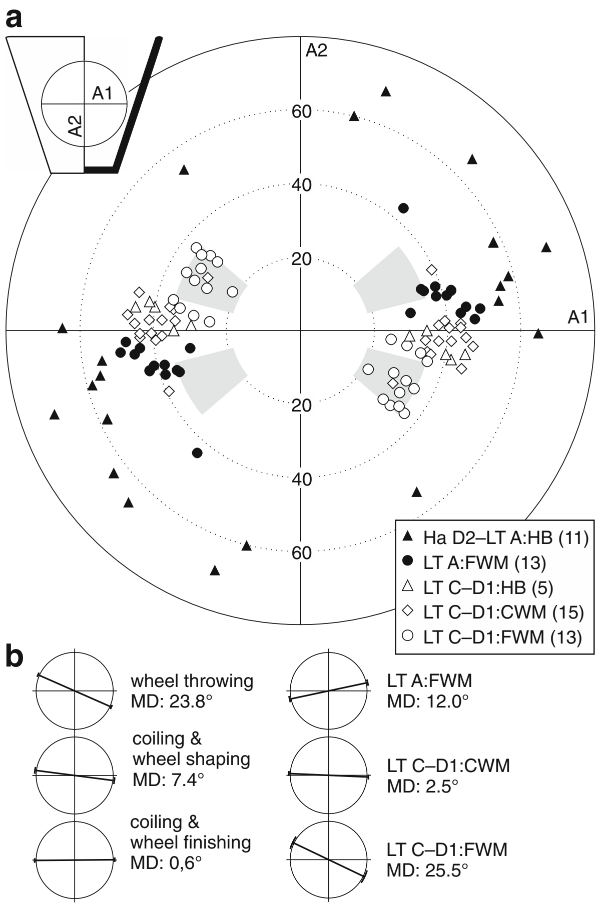

Fig. 9 **a** Polar diagram of the mean direction with the circular standard deviation of objects in tangential sections taken from the La Tène pottery from the Chrudim region (for the legend, see Fig. 8, the *numbers in the parentheses* indicate the number of samples). The *grey areas* in the diagram define the values typical for wheel throwing with clockwise rotation (*lower left and upper right quadrants*) and with anticlockwise rotation (*upper left-hand and lower right-hand quadrants*). All the potters that contributed to the experimental collection throw in the anticlockwise direction. The area for throwing in the clockwise direction is constructed theoretically, based on the assumption that, if no variables other than the direction change, then the orientation pattern relative to the direction is the same. **b** Comparison of the mean directions of wheel throwing xand coiling in combination with wheel shaping and finishing (all thrown in the anticlockwise direction based on the experimental data presented on Fig. 4) with the mean directions of the sampled La Tène wheel-made pottery. The graphs show the average orientation (*thick line running through the centre of the graph*) and the 95% confidence interval (*curves from the ends of the thick lines*). *MD* represents the mean deviation from the horizontal axis. Outliers were excluded from the calculations

among the firing procedures. A significant difference in this respect is found between hand-built and wheel-made pottery. While the proportion of asymmetrical colour layering leaving lighter surface zones on hand-built pottery throughout the studied period reaches 30–50%, it is well below 5% for fine wheel-made pottery (Fig. 12). A dominance of symmetrical parallel patterns is characteristic for La Tène A and La Tène C–D1 fine wheel-made pottery. La Tène C–D1 wheel-made coarse ware also shows a significant proportion of symmetrical parallel patterns (more than 40%).

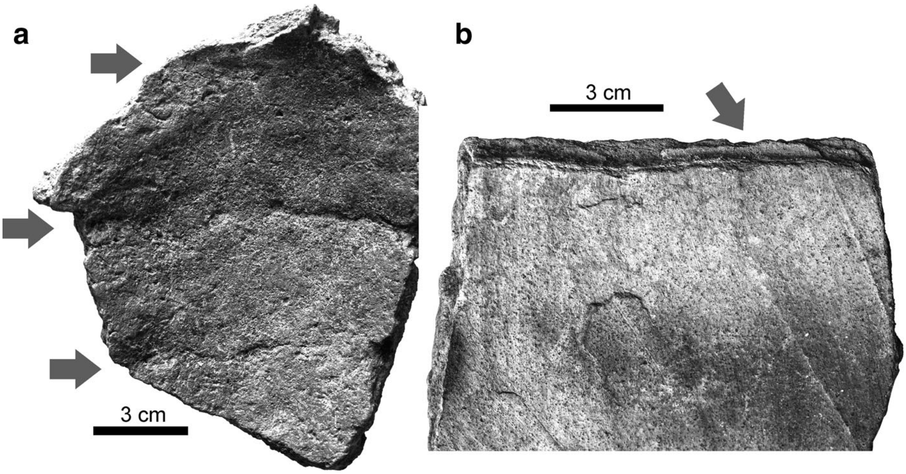

Fig. 10 Joins between segments macroscopically observable on the La Tène A hand-built pottery (**a**) and the La Tène C–D1 pottery (**b**)

Hypothetically, this group is composed of pottery fired using various methods reflecting the technological diversity of the production of coarse wheel-made pottery in this period.

Provenance

The basic compositional groups of Tuněchody fine ware correspond to the chronological phases of the settlement (Fig. 13a). The first group consists of hand-built pottery dated to Hallstatt D2–3. Samples from a subsequent chronological phase (Hallstatt D3/La Tène A1) extend between the groups of the first and the third settlement phases, which correspond to the La Tène A1 wheel-made pottery. A small proportion of the first wheel-made pottery can be found within the compositional group of the previous phase (Hallstatt D3/La Tène A1). The wheel-made pottery from the third and the fourth settlement phases forms clearly distinct compositional groups, but, like the La Tène A1 wheel-made pottery, a small proportion of the La Tène A2 wheel-made pottery also belongs to the compositional group of the previous settlement phase. The occurrence of pottery made from traditional materials along with new predominantly fine-grained wheel-made pottery could reflect an overlap of the two practices.

The wheel-made pottery from the other two sampled La Tène A sites falls (with exceptions) within the similarly dated groups of pottery from Tuněchody. The La Tène A1 wheel-made pottery from Mikulovice corresponds to the Tuněchody third settlement phase group and the La Tène A2 pottery from Mikulovice and Chrudim-U sv. Kříže to the fourth settlement phase group. Thus, the main compositional groups of the La Tène A wheel-made pottery do not correspond to site-specific groups, but rather to a period-specific classification (Fig. 13a).

In contrast, wheel-made pottery from each of the La Tène C–D1 sampled settlements belongs to a distinctive compositional group (Fig. 13b) suggesting multiple site-

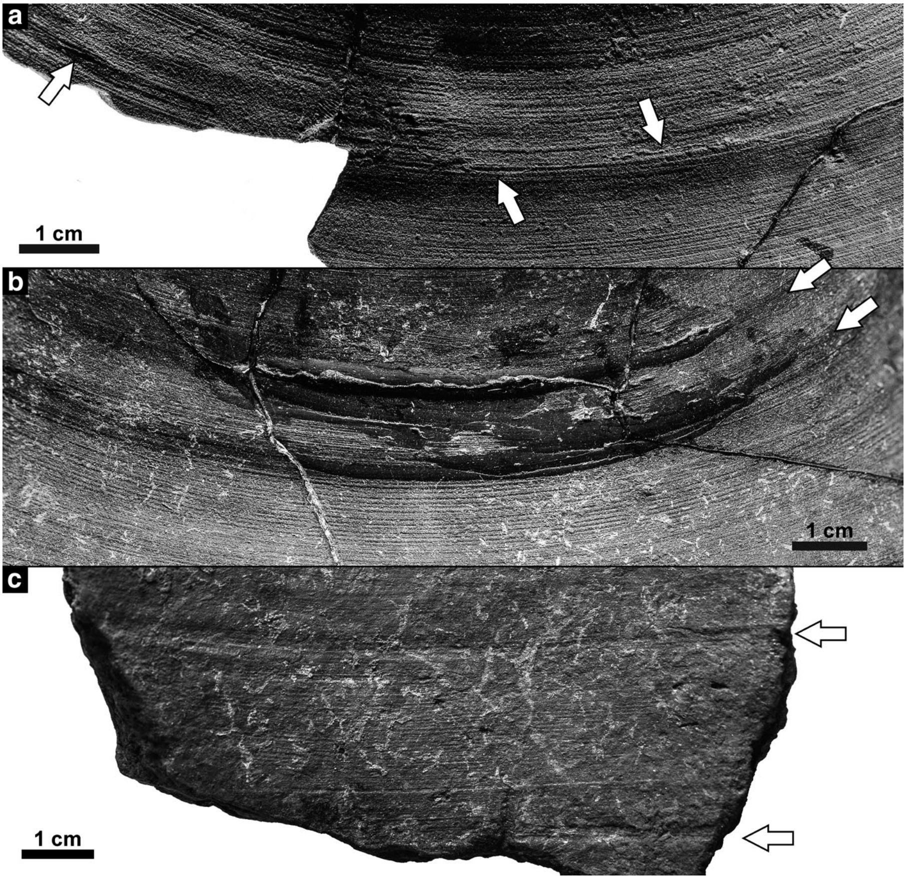

Fig. 11 Macrocopic evidence for composite techniques on the La Tène A wheel-made pottery. **a** Residue of an incomplete coil join on the interior of a wheel-made bottle in combination with preferential horizontal breakage. **b** The potter noticed incomplete coil joins on the interior of the bottle neck during polishing of the exterior of the vessel and tried to obliterate them by using a polishing tool. **c** Seams that resulted from lack of surface smoothing to obscure the juncture between segments

specific sources in the region. No pottery compositionally similar to the typical pottery from the sampled kiln sites (Brčekoly and Chrudim-Za Sklepy) was identified in the surrounding settlements (see Thér *et al.* 2014).

Most of the clays used in the fine ware production have similar mineralogical and petrographic features. An anisotropic matrix with microcrystalline character is typical for illitic clays (Ionescu *et al.* 2007), and the mineral and rock grains are usually well rounded to subrounded. Tiny crystals (below 0.1 mm) of muscovite are very common. These observed features correspond to the local fluvial sediments which were used as basic ceramic raw materials in all the studied chronological phases.

The compositional analysis also pointed to potentially non-regional pottery. The frequency of non-local pottery in the late Hallstatt contexts (Fig. 14) is

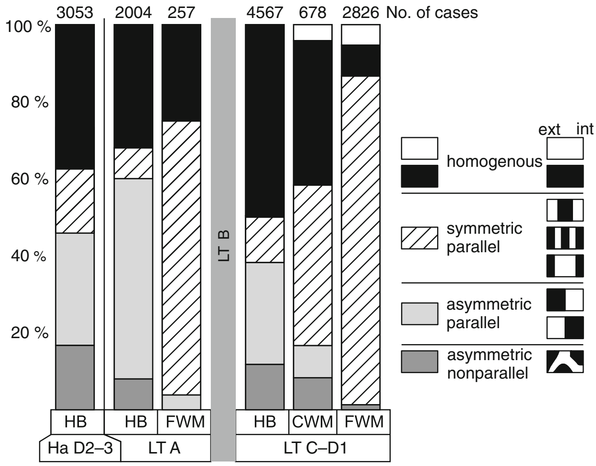

Fig. 12 Comparison of colour patterns on pottery wall sections (for the legend, see Fig. 8)

interesting. Petrographic analysis has revealed more information about the origin of this pottery or of the raw materials. Three specific petrographic groups of non-local origin were distinguished among the Tuněchody Hallstatt D2–3 and the La Tène A hand-built fine ware: with the presence of (1) angular fragments of amphibolites and angular grains of epidote, (2) fragments of granites to diorites and (3) mica schists and crystals of muscovite and biotite over 1 mm in size. All these samples represent different raw material sources, indicating two different regions of origin: the materials of the first and second petrographic groups probably originated in the Železné hory Mts. and the materials of the third petrographic group probably came from the Kutná Hora Crystalline Complex west of the Chrudim basin. The non-local petrographic groups mostly represent hand-built pottery dated to settlement phases preceding the introduction of wheel-made pottery (Fig. 14).

Synthesis and Discussion

The technological and provenance analyses of pottery from the late Hallstatt and the La Tène period in the Chrudim region suggest substantial differences in production of wheel-made pottery. The basic findings related to the introduction of wheel-made pottery in the La Tène A period are as follows:

1. Wheel shaping was commonly used in manufacture of newly introduced fine ware, and there is no evidence for the use of wheel throwing.
2. All the sampled wheel-made pottery was rotated in the clockwise direction.
3. The manufacturing process of the first wheel-made pottery differs from traditional hand-built pottery in all the basic steps: paste preparation, primary and secondary forming techniques, decoration and firing.

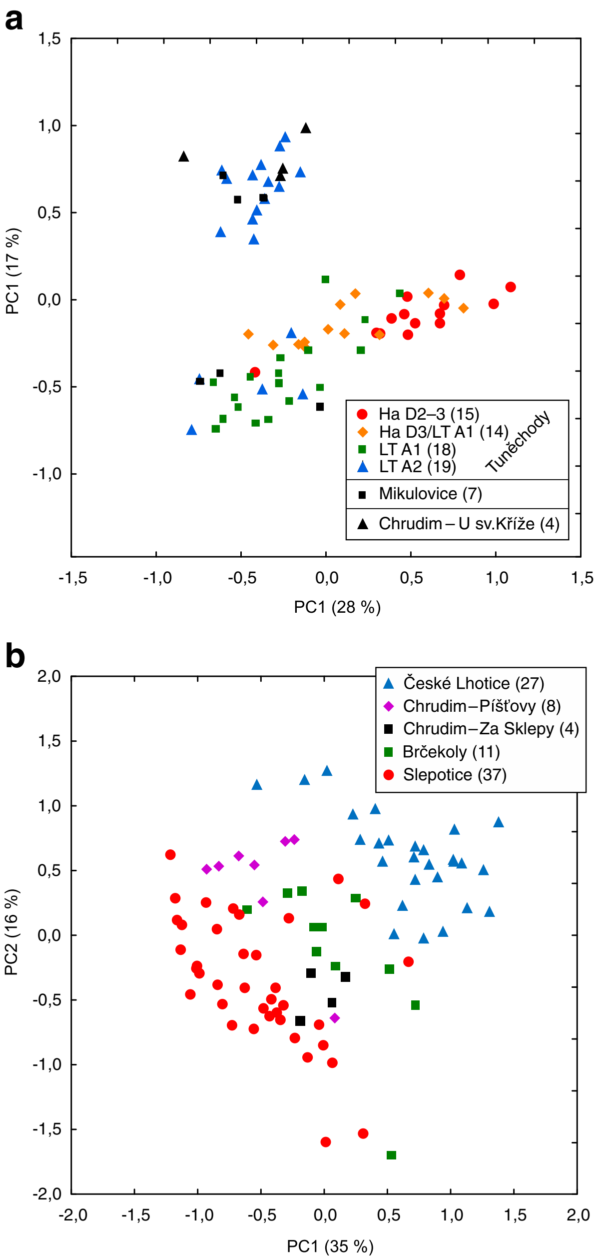

Fig. 13 Evaluation of geochemical data by principal component analysis. Scatterplots of the first two component scores of pottery samples of the Hallstatt D2–La Tène A fine ware (**a**) and the La Tène C–D1 fine ware (**b**) (the *numbers in the parentheses* indicate the number of samples)

4. The majority of the wheel-made production was manufactured from the clay of the same origin which suggests one production centre within the region.

5. The use of the technique was restricted to the manufacture of fine tableware with carefully executed surface finish (Fig. 15a).
6. Ceramic material used for production of wheel-made pottery underwent a rapid transformation during the La Tène A period towards the use of fine-grained pastes. The new fine-grained material has a different origin than the clay used for manufacture of wheel-made pottery at the beginning of the La Tène A period.

It is apparent that the emergence of fine wheel-made pottery in the region at the beginning of La Tène A represents a clear technological discontinuity. The divergence between the wheel-made pottery and the rest of pottery production reflects a striking contrast in the traditions expressed by the exerted skills and materialised in the products. It does not seem probable that pottery made from a different mixture without any indication of the use of rotation in forming and fired using a different procedure could have been made by a potter belonging to the same learning network as a potter who made fine ware using a rotational device.

The restricted number of workshops producing wheel-made pottery, the significant decrease in the amount of evidence for extraregional pottery and the abrupt change in ceramic materials during the period (regardless whether this meant technological changes during the development of the new technology or the establishment of a new production centre of wheel-made pottery) all conform to the transmission of the novelty in a restricted learning network.

The identified wheel-shaping technique is a skill-demanding activity that requires substantially more time to learn than common hand-building techniques and intensity of production sufficient to maintain the required skills. This indicates that potters who were using the technique were economically dependent on this production. On the other hand, wheel shaping had no potential to be more efficient in terms of the time needed to complete the vessel compared to the identified hand-building techniques.[9] Therefore, the practical performance of the use of rotational energy in forming did not provide benefits over traditional alternatives, quite the contrary. Visual performances of the products are clearly distinguishable from hand-built pottery. The repertoire of wheel-made shapes is restricted to bowls (cups) and flasks, utensils intended for serving drinks, which suggests a connection with feasting—an arena for social competition whose importance has been stressed in the social practices of the Iron Age communities in Europe (Dietler 1990, 1996). The shape repertoire comprises extravagant skill-demanding shapes such as lens-shaped flasks (Schwappach 1975). The body of this

[9] General findings on the time efficiency of the wheel-shaping technique (*e.g.*, Nicklin 1971; Roux and Courty 1998) are supported by our observations made during experimental replication of the manufacturing process of the La Tène pottery. The forming of bowls as the dominant shape of the La Tène A wheel-made production had similar time requirements when coiling, slab building and their combination with wheel shaping were used on the condition that the task is to complete a vessel of the same shape, size and average wall thickness, not to achieve comparable regularity of the walls. This can be applied to the archaeological pottery in the study, as the walls of the La Tène A wheel-made pottery are significantly more regular than the walls of hand-built pottery.

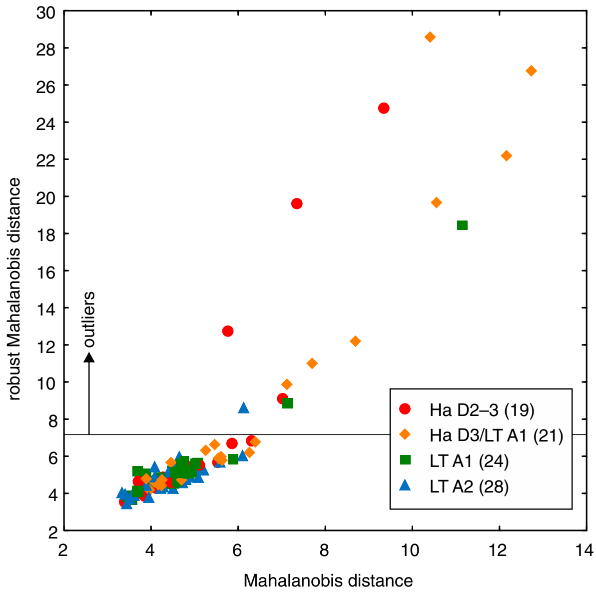

Fig. 14 Outlier detection for the compositional data based on the robust Mahalanobis distance. The biplot shows the classic Mahalanobis distance versus the robust Mahalanobis distance of the Hallstatt D2–La Tène A fine ware from the Chrudim region with the delineated zone of outliers (*the numbers in the parentheses* indicate the number of samples)

vessel is an ellipsoid with large maximum diameter/height ratio; acute angles between different parts of the vessel are characteristic, and mechanical stress is increased by the mass of the tall neck. Moreover, forms and decorations are related to the newly developed unique La Tène style of luxury items initially associated with rich burials in the area centred in the Rhine and Champagne regions. The style represents creative transformation of Mediterranean, East European, and Hallstatt artistic components (Megaw and Megaw 2001; Harding 2007). Rounded curves of vessels with plastic bars, ribs and grooves contrast with traditional vessel contours. Stamped decor creating

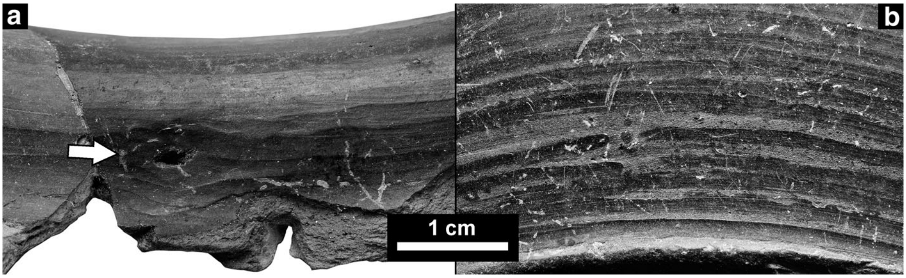

Fig. 15 Typical polished surface of LT A wheel-shaped (**a**) and LT C–D1 wheel-thrown (**b**) pottery. **a** Careful time-consuming polishing: the entire surface was polished leaving no unpolished areas. Highly curved areas or surface unevenness that could not be reached by the polishing tool when the vessel was rotating were subsequently polished without rotation (a carefully polished small depression around a removed large inclusion is marked by an *arrow*). **b** Careless polishing: rapid lifting of the polishing tool during rotation left unpolished strips on the surface of the vessel. The areas inaccessible to polishing during rotation of the vessel were usually left unpolished

a combination of interlinked circles, arcs, crescents or lotus buds contrasts with incised, polished or painted triangles, strips or grids found on hand-built pottery (Fig. 6). This indicates that the product played a more significant role in the adoption of the technique than the process itself. We can even suggest that desire for the product outweighed the disadvantages of the practical performances of wheel shaping, *i.e.* initial spreading of wheel-made pottery can be seen as a product innovation.

Based on stylistic and technological attributes of wheel-made products in relation to the rest of the pottery production and the character of production, we can propose the hypothesis that the first wheel-made pottery represented an item of high social value produced by a specific group of potters. Such value enabled the development of organisational forms of production, allowing the long apprenticeship necessary to develop and maintain technological behaviour requiring a high level of motoric skills in a field of technology that uses broadly available raw materials. The requirements of the production imply that some reciprocal system had to be at work to ensure the reproduction of wheel-made pottery production. We propose two models of such a reciprocal system:

(a) General demand for the new, socially charged items stimulated the evolution of organic solidarity between the incoming potters and the rest of the society. The potters themselves controlled the transmission of this knowledge and consequently, the value of their products and prevented dissemination into the local potting community. The transmission barriers were naturally facilitated by the dissimilarity of the required skills and the difficulty of learning them compared to traditional techniques.

(b) The new socially charged items attracted attention among the elite in their pursuit to control or create sources of power in competitive network systems. The elite had resources to secure the adoption of discontinuous technological innovation, *i.e.* to sponsor-specialised producers (attached specialists in the sense proposed by Earle 1981; *cf.* Brumfiel and Earle 1987; Costin 1991; Costin and Hagstrum 1995). Control over production, facilitated by the principles mentioned in the previous model, enabled the elite to define the conditions under which the pottery was distributed. Individuals of the highest social status also acted as leaders of opinion promoting the innovation. Potters benefited from a symbiotic relationship with the elite and participated in control of transmission of knowledge and skills.

To discuss these alternatives, we need to consider the social context of the innovation. At the beginning of the La Tène period, marked social differentiation is reflected in the accumulation of wealth in burials (for discussion of the social changes in transition between the Hallstatt and the La Tène periods, see, *e.g.*, Frankenstein and Rowlands 1978; Kristiansen 1998; Pauli 1980, 1984; Bintliff 1984; Nash 1985; Dietler 1989, 1995; Brun 1995; Pare 1991). Imported artefacts played a vital role in the expression of social status. Their number increased over time and culminated in the Hallstatt D2–La Tène A periods (Brun 1995; Pape 2002; Hauser and Schönfelder 2014). The structure of imports found in Central Europe demonstrates the extent of direct or indirect contacts with remote regions. Etruscan bronze vessels, Greek pottery and glass artefacts from various Mediterranean workshops are the predominant archaeologically traceable luxury items coming from the Mediterranean area. The dispersed settlement pattern of small villages and farmsteads with no obvious centres of production suggests self-sufficient units with economic basis in agropastoral activities (Collis 1995; Kristiansen 1998). There is no evidence for specialisation in production of utilitarian goods made from commonly available materials.

The evidence for vertical differentiation of social statuses and their expression in material culture favour the model of engagement of the elites in the adoption of wheel-made pottery. However, attributes of production can be misleading in interpretation of the organisation of production and significance of the products (*e.g.*, Day *et al.* 1997, 2010; Van de Moortel 2002). If we are proposing that production of wheel-made pottery was connected with elites, then it seems to be useful to look at consumption patterns. It is usually assumed that if wheel-made pottery is to be a valued item shaping the social status of the individuals who own it (prestige item), then it should be selectively distributed in correspondence with the occurrence of other attributes of higher social status. At first glance, it might seem that the distributional pattern contradicts the notion of controlled production of high socially value items. Wheel-made pottery is documented in small amounts but widely distributed in open lowland settlements. This picture is supported by observations in other regions (Lang 1974, 1976; Gosden 1983; Pauli 1993; Stöllner 2002; Tappert 2006, 2012; Augier *et al.* 2013; Balzer 2015). However, two problems are entailed in the interpretation of consumption patterns in this case.

The first problem is that we are not able to reliably associate the distribution of wheel-made pottery with the location of elites in this period. The La Tène A hillforts are known, but their number dramatically decreased compared to the Hallstatt D period and they were unevenly distributed across the landscape (Chytráček and Metlička 2004). It seems that they played specific roles in the early La Tène society (*cf.* Hill 1995; Hamilton and Manley 2001 for analysis of the Iron Age hillforts of southern Britain), and the majority of the wealthy population lived in open lowland residences (*e.g.*, Krause 2005; Krause *et al.* 2010) that were barely discernible from other settlements. The distribution of Mediterranean imports is in accordance with this picture (for imports in Bohemia, see Trefný 2011).

The second, more fundamental problem related to interpretation of the distribution in terms of the prestigious character of the products is the implication that control of the production of socially valued items by the elite leads to archaeologically recorded selective distribution of these items. The category of prestigious items rises from the need to express a social value and the use of it in social communication. If prestige goods are to fulfil their social purpose, then, they have to be consumed: given, destroyed or sacrificed (*e.g.*, Ekholm 1972; Friedman and Rowlands 1977; Douglas and Isherwood 1996). Valuables are commonly excluded from the exchange of domestic goods using various mechanisms (*e.g.*, Douglas 1967; Gregory 1982; Appadurai 1986; Gosden 1989; Douglas and Isherwood 1996). The exclusion is usually facilitated by control over the production and exchange (*e.g.*, Sahlins 1958; Uberoi 1962; Firth 1965; Fried 1967; Friedman and Rowlands 1977; Dupré and Rey 1978; Godelier 1978; Strathern 1979; Wolf 1982; Feil 1984; Earle 1987; Peregrine 1991; Blanton *et al.* 1996; Douglas and Isherwood 1996). The restrictions create a discrete sphere of exchange in which only high-ranking articles circulate, but this does not mean that only high-ranking individuals can enter this exchange. Valuables constitute means of social negotiations particularly within societies with gift exchange as a basic mechanism of the communication of goods, where the value of the goods is directly affected by the attachment of personal attributes to the exchange process (Mauss 1925; Lévi-Strauss 1969; Gosden 1989; Bell 1991). The reciprocity of exchange of prestige goods is principally asymmetrical when it is implemented in communication between individuals in different social levels. Gifts create ties related to their perceived essence and worth. Principally, members in lower social position receive gifts as a way to strengthen their social status, but they cannot repay gifts of prestigious items because there is no impersonal exchange equivalent to express their value. To accept without the ability to return is to face subordination (Mauss 1925; Sahlins 1974; Orenstein 1980; Gosden 1989; Cobb 1993). Therefore, the mechanism of exchange of socially valued items interconnects individuals within the entire social spectrum, not only those at the top of the social structure. The focus on the materialised identity of the elites masks the basic role of prestige goods in social life.

The prestige goods are not an indifferent class of articles of the same social value (Gosden 1989). We can assume that local wheel-made pottery did not belong to the highest ranked goods, and, as such, it was distributed primarily within the polities. The regional production of the La Tène A wheel-made pottery is in concordance with this picture. The “regionality” of the production and distribution would depend on the geographical extent of intra-polity relations.

Consequently, wide distribution of goods cannot be taken as evidence against their role as prestigious items or against control of their production or distribution. Powerful individuals or institutions can control the conditions under which they are distributed (not where the goods end up), and control of production allows them to determine these conditions.

Extensive social negations involving exchange of prestige goods as one of the basic mechanisms are characteristic for societies with a network political-economic strategies in which the individual political actors build their positions around control of sources of power (Blanton *et al.* 1996; Feinman 2001; *cf.* “individualising chiefdoms” in Renfrew 1974; low “grid” and “group” social environment in Douglas 1978; “wealth” financing of hierarchical structures in D’Altroy and Earle 1985). These political strategies imply considerable potential for competition and conflict between individuals with overlapping political networks. Consequently, leadership tends to be turbulent and unstable (Strathern 1969; Modjeska 1982; Blanton *et al.* 1996). This would result in a mixed archaeological picture with no apparent settlement hierarchies or selective distributions of even the most highly ranked prestigious artefacts leaving evidence for association of the accumulation of wealth with individuals in funerary practices as the only mark of social inequality. The archaeological evidence of the early La Tène period indicating emphasis on warfare, personal wealth and the consumption of elaborate prestige goods is in accordance with this picture.

We conclude that the best-fit scenario for explanation of the results of the presented analysis is the engagement of powerful individuals of high social status in the introduction of wheel-made pottery during the La Tène A period. They probably acted as leaders of opinion and created mutually advantageous relationship with potters. Reflection of association of the elite with the introduction of wheel-made pottery can be seen in the subsequent development. In the La Tène B period, dispersed settlement and lack of exceptionally rich burials implying “levelling” of the social structure (Bintliff 1984; Collis 1995; Wells 1995; Brun 2007, 2016) are characteristic for all the parts of Central Europe. In Bohemia, a regression in decorativeness and technological standard and small proportions of wheel-made pottery can be observed in the La Tène B–C1 period (Salač and Smrž 1989; Rulf and Salač 1995; Salač 1996). This is also true of the Chrudim region, where the lack of assemblages of wheel-made pottery reliably dated to this period prevents representative sampling. The disappearance of rich elite burials coincides with the degradation of wheel-made production in Bohemia.

This picture should not be regarded as representative for the introduction of wheel-made pottery in Central Europe as a whole. Central Europe during the late Hallstatt and early La Tène periods comprised communities in various social configurations sharing some common cultural traits. In the presented case, we considered a small, rather peripheral region with low population density, supposedly simpler intergroup economic relations and a small range of social networks, resulting in a low degree of cultural interconnectedness compared to other regions in the early La Tène Central Europe. Such an environment could seemingly paradoxically create suitable conditions for the control of wheel-made pottery production. There were no conditions stimulating the development of independent craft specialisation, and local technologies could supplement poorly accessible luxury imports.

Finally, we would like to draw attention to the change in the direction of rotation. The early La Tène wheel-made pottery was formed with rotation in the clockwise direction. At least from the La Tène C period, all the sampled wheel-made pottery was formed with rotation in the anticlockwise direction. Although some scholars have suggested that the direction of rotation depends on the type of rotational device (Czysz 1990), the manner in which the device is used has more to do with individual potting techniques than the design and mechanical efficiency of the device itself (cf. Jeffra 2011). This significant habit change points to the dynamic transformations typical for restricted learning networks causing volatile transmission of technological knowledge.

The results of the analysis for the La Tène C–D1 period pottery in the Chrudim region yield a picture considerably contrasting with the La Tène A period:

1. Wheel throwing occurred as a common practice in forming fine ware, along with the use of other wheel-forming techniques.
2. Rotational energy was also used in forming coarse ware, but only wheel finishing was identified in this case. Primary forming techniques employed in the production of wheel-finished coarse pottery were similar to the forming techniques of hand-built pottery.
3. All the sampled wheel-made pottery was rotated in the anticlockwise direction.
4. Clear technological differences (apart from the use of rotational energy) cannot be observed between potters who used a rotational device and who did not. We can observe the use of various clay mixtures and firing procedures with no exclusive

association with wheel-made or hand-built production with one exception, fine-grained pastes, which were used almost exclusively for the production of wheel-made pottery (sampled fine-grained ceramics show the application of wheel shaping and throwing).

5. Identification of multiple site-specific sources of ceramic materials used in the manufacture of wheel-made pottery in the region implies the existence of multiple pottery workshops utilising rotational devices and producing pottery for local consumption.

The diverse use of rotational energy in the forming sequence and its use in the forming of various ceramic materials (most of which were also used in concurrent hand-built production) and the existence of multiple workshops producing wheel-made pottery with distribution restricted to the local communities imply an open learning network resulting in diverse chaîne opératoires combining various practices from the technological pool of the period. However, the combinations were not entirely random. We can observe an association of particular wheel-making practices with particular pottery.

Wheel shaping and wheel throwing were employed for the same type of pottery—tableware made from fine-grained materials.[10] There is no reason why the same potters would use a different technique to manufacture the same types of pottery. Consequently, the observation points to at least two separate traditions connected with transmission of wheel-making practices, probably reflecting spreading of wheel throwing at the expense of wheel shaping within the La Tène C–D1 period, which cannot be reliably traced because it is below the current chronological resolution. In contrast, wheel finishing was used to manufacture a broad repertoire of coarse ware ranging from bowls with in-turned rims to storage jars, which was the same repertoire that was also manufactured using hand-building techniques. What is the logic behind these associations? We can envision either the same potters manufacturing fine ware and coarse ware using different techniques or the product specialists focused on manufacturing fine ware or coarse ware. The archaeological evidence is not conclusive in this respect, but detailed analysis of production of pottery kilns in the Chrudim region suggests the earlier alternative (Thér *et al.* 2014). The degree of contribution of rotational energy in forming can be related to the general level of throwing skills reflecting the intensity of production. Hypothetically, the intensity of production of wheel-made pottery in the region was generally sufficient to acquire and maintain the skills required for efficient throwing of smaller vessels from plastic fine-grained materials, but it was too low to make the application of wheel throwing for the production of larger and/or coarser utilitarian ware a viable alternative to hand-building techniques (*cf.* Cardew 1969; Nicklin 1971).

The use of rotation in forming coarse ware could simply reflect the habitus of potters who learned how to form clay using a rotational device. Thus, hypothetically, there was no cultural fitness in wheel finishing of coarse ware

[10] An exceptional example of a wheel-thrown coarse pot, which can be seen in Fig. 9, does not belong to the local groups of pottery based on geochemical and petrographic analyses.

and the transmission of this practice was dependent on the cultural fitness of wheel throwing of fine ware. The estimated time needed to complete common La Tène bowls is approximately four times shorter when wheel throwing is used instead of the other wheel-forming techniques (Thér *et al*. 2015). Thus, we can assume that time efficiency was the process performance that was substantial for the cultural fitness of the technique. The careless surface treatment of wheel-thrown fine ware from this period (Fig. 15b) supports such a hypothesis. The advantage of the time efficiency depends on its significance in a given socio-economic context measured by the cost of skill acquisition and maintenance. Therefore, wheel throwing time efficiency could have played a significant role in adoption of the technique in those environments where the pottery craft was intensively performed and essential for the livelihood of the manufacturers and the products entered a market operating largely through impersonal considerations of value based on supply and demand. Under these conditions, the efficiency of production is an ingredient in the success of a potter and, consequently, a precondition for imitation of the potter's behaviour. In other words, conditions for interhousehold division of labour in pottery production and the existence of market-based exchange would create a selective environment in which the efficiency becomes a significant component of the cultural fitness of wheel throwing.

Can we expect the development of a selective environment favouring the spread of wheel throwing in the later stages of the La Tène period? Archaeological evidence suggests that craft production remained on a very small scale until the second half of third century BC, when concentration of metalworking debris and the remains of other non-agricultural activities have been found at certain open lowland settlements along with evidence for increasing long-distance exchange of bulk goods (Büchsenschütz 1995; Collis 1995; Cumberpatch 1995; Salač 1996, 2011; Augstein 2006). These settlements constituted the focal points for extensive exchange in a diversified economy with growing complexity. Increasing use of coins was symptomatic of this process which culminated in the emergence of oppida—fortified settlements with habitation area much larger than the space enclosed by hillforts in previous periods. Their exact role is not clear, and a wide diversity of different phenomena is subsumed under this term. However, whatever their diversity means and whatever their exact role in the late La Tène society (for a discussion, *e.g.*, Collis 1984, 1995; Brun 1995; Büchsenschütz 1995; Crumley 1995a; Wells 1995; Salač 1996; Venclová 2002; Augstein 2006; Danielisová 2011), it is apparent that they are the result of nucleation of the population at various social levels. The concentration of non-agricultural production in oppida is well documented (Collis 1984; Venclová 2002), but this evidence does not imply that their economy was based on non-agricultural production (Danielisová and Hajnalová 2014), but rather that the nucleation was accompanied by an intricate division of labour.

The appearance of oppida demonstrates the emergence of social formations capable of constructing massive architectural features, but there is a lack of evidence for domination by particular powerful individuals (Renfrew 1974). Written sources describe a decentralised system of power and indicate that the phenomenon of oppida cannot be attributed to the direct political activities of elites (Büchsenschütz 1995; Thurston 2009). Crumley (1987, 1995a, b) proposed a heterarchical structure of political power with complex socio-economic relations, widening social networks and increasing the interconnectedness of society within the context of the oppida. This environment strengthened economic interdependence between groups and made society as a whole more reliant on exchange. Apart from oppida, evidence for specialisation of regional production (Venclová 2001, 2008c) suggests growing organic solidarity without apparent hierarchical components. A market as a form of exchange qualitatively different from forms entailed in personal obligations (Hodder 1980; Gosden 1989; Kipp and Schortman 1989) is a natural ingredient of such an environment.

Considering these circumstances, the emergence of wheel throwing in the later stages of the La Tène period can be explained by changes in the socio-economic context of pottery production that created a selective environment favouring time efficient, although skill-demanding, processes. Consequently, the spread of wheel throwing can be seen as a process innovation, unlike the emergence of wheel-made pottery in the La Tène A period. The evidence for multiple local workshops producing fine ware is in accordance with this interpretation.

Conclusions

The variability of phenomena related to the use of rotational energy for pottery forming in the La Tène period indicates various mechanisms of cultural transmission which were at play in the evolution of the technology in the La Tène society. Interpretation of the observed phenomena was approached especially through a distinction between the product and process innovation and the transmission of cultural traits in open and closed systems.

We have argued that innovations can be regarded as product innovations, even in cases where the process undergoes significant changes. The distinction depends on what played a key role in the innovation process: the technological process or its product. This has significant implications for the mechanism of adoption of a novelty. The potential of the product to play a key role depends on the observability of the effects of the manufacturing process on the product, *i.e.* on its distinctive sensory performance.

The introduction of pottery formed using a potter's wheel at the beginning of the La Tène period represents a clear technological discontinuity in terms of the ceramic paste preparation, the entire forming sequence and the firing procedure. The identified forming sequence is a time-consuming and skill-demanding activity. The clear technological divergence between wheel-made pottery and the rest of pottery production reflects a divergence of identities within the potting community. The results, together with evidence for one main production centre of wheel-made pottery operating in the region during the La Tène A period, can be interpreted as being the consequence of transmission of the novel technology in a restricted learning network. Not the process performance characteristics but the product visual performance was probably the trait under selective control, and we can assume that the elite played a substantial role in the introduction of this pottery.

In contrast, during the La Tène C–D1 period, wheel-made pottery was produced in a number of local pottery workshops. The diverse use of rotational energy has been identified. Wheel throwing occurred as common practice in forming fine ware along with the use of wheel shaping. Rotation was also used in forming coarse ware. Clear technological differences (apart from the use of rotation) between those potters who used a rotational device and those who did not cannot be observed. The diversification of the use of a potter’s wheel can be linked to changes in the selective environment caused by increased socio-economic complexity in the period. The results suggest the existence of independent specialists sensitive to cost-effective production techniques. Thus, the emergence of wheel throwing in the later stages of the La Tène period can be viewed as process innovation, unlike the emergence of use of rotational energy in pottery forming in the La Tène A period.

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